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Performance Evaluation of DG in Distribution System: An Extensive Review

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Abstract

The review paper provides a brief introduction of Distributed Generation (DG) in Distribution System (DS). This study prime objective is to evaluate the DG performance in DS. DG sources are considered to play a pivotal role in DS owing to the growth of electrical energy demand. DG with reference to its potential in using alternative energy resources offers a promising future for forthcoming power generation networks. The contribution of DG to power networks include enhancement in reliability, power quality, security, and energy efficiency. These benefits can be achieved through optimal distributed resource allocation considering distinct constraints, objective function, and using appropriate optimization methods. Existing literature provides a detailed analysis of several techniques employed for DG in DS. A comparative analysis is presented which incorporates the objectives of the proposed study and the observations and future scope are tabulated.

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1 Introduction

The exponentially rising electricity demand has led to the depletion of conventional sources of power generation. These sources are centrally operated and are unsuitable for cost and environmental issues in the current liberalized power market. Providing electricity in a decent, cost-effective, and reliable manner to customers is the prime motive of utilities. In this regard, Distributed Generation (DG) presents solutions to these problems up to a certain extent. DGs own small-sized units, they can be energized by non-renewable and renewable sources and need less region for installation (Arabali et al., 2017). Due to these characteristics, they are extensively employed in electrical Distribution Systems (DSs). DGs are power generation sources that are connected directly to customers' end. Moreover, optimally positioned DG units minimize system losses, enhance voltage security, system reliability, voltage profile, power quality, and voltage stability. Additionally, DGs are proficient in alleviating voltage sags, harmonics significantly. Hence placing DG in DS is highly beneficial for both utilities and customers (Behera et al., 2019). Apart from these advantages, it also has certain impediments if it is not positioned at optimal locations. It may cause stability, frequency, and protection issues. Furthermore, the development of modular DGs requires lower investment, lesser construction time, and smaller space. As a result, DG has become the trending topic of research nowadays.

Recently, electrical systems are experiencing various environmental, economic, and technical problems. A feasible means to relieve such problems is to utilize DG units. The involvement of these units has been more crucial with the deregulation of the electrical industry. Furthermore, DG units are relevant options for DS operators in order to satisfy their customer requirements (Galiveeti et al., 2018). The literary findings strongly approve that location, size, and type of DG units in DS substantially affect the environmental, economic, and technical objectives of DS. Determining optimal DGs size, location, and type in DS are entitled as DG allocation. Moreover, appropriate DG installation in a suitable location with suitable size will considerably minimize system losses. Through power generation closer to load centers DGs eliminate the necessity of transmitting bulk power, thereby reducing stress on electric transmission networks. DG's are considered the best option for electrifying remote areas wherein distribution and transmission costs are very high. DG's enhance the diversity of electric sources, competition among power industries, enhance power quality, and reduce power cost for users (Tanwar et al., 2016).

Despite these gains, DG's experience some challenges. DSs initially were constructed and designed to handle power flow in only a single direction. However, DG unit insertion led to bi-directional power flows that particularly disrupt and affect the protective relay's performance. Furthermore, in DSs with DG, the islanding might occur. Islanding results in overvoltages, extreme power losses and might jeopardize the public and crew. Improper DG positioning and sizing might lead to stability problems. Thus it is crucial to consider all these mentioned factors while using DG in DSs. In deregulated power scenarios, Distributed Generation (DG) is considered to be an efficient method for handling control, operation, and performance of Distributed System (DS). For DG management, techniques available in existing literature are unable to simultaneously offer economical and technical benefits. Hence an efficient methodology is needed to enhance economical as well as technical benefits compared to existing schemes.

2 LITERATURE REVIEW

A detailed review of optimal siting and sizing methods for DG in DS was presented by Prakash et al. (2016). In this work, using DG fundamentals and methods, the traditional and heuristic schemes for optimal placement and sizing (OPaS) were DG parts in DS, and their effects on customers and utilities were reviewed. Consequently, this study also presented the effects of DG insertion on DS performance and operation, power quality, reliability, system losses, voltage stability, load ability, voltage profile, etc. Furthermore, a comparison of met-heuristic and traditional techniques for OPaS in DS was presented. The study revealed that traditional methods are computationally inefficient for complex and huge systems. Moreover, the study highlighted that for determining global optimal substitute of a multi-objective, complex issue use of hybrid methods by combining two or more optimized meta-heuristic schemes confer a more reliable and effective optimal solution. The work further emphasized using novel heuristic optimization methods for achieving better outcomes in future analysis.

Perveen et al. (2016) presented An approach for identifying faults and for achieving optimal overcurrent relay coordination in an offshore wind farm (OWF) associated with an onshore grid. In this work, the detection potentials of various signal processing methods, empirical mode, Hilbert transform, and Stockwell transform were investigated for localizing distinct kinds of faults. Additionally, fault instances at the grid and instances with variations in operating factors were simulated and studied. Moreover, analysis for identification of faulty cases by computing mean and maximum indices, abrupt time indices of the faulty signal was presented. The mean and maximum indices helped in distinguishing faulty and normal signals in DC and AC faults. Furthermore, optimal overcurrent relay coordination using Gravitational Search Algorithm (GSA), Particle Swarm Optimization (PSO), and Genetic Algorithm (GA) was discussed. These techniques were then compared to hybrid optimization schemes for achieving efficient relay coordination. This study also highlighted the use of hybrid optimization schemes for attaining superior outcomes in future analysis.

Pandi et al. (2012) presented a method for determining the size and location of DG resources considering protection and harmonic coordination limits. The prime motive of this work was to optimize the penetration level of DG from DG units considering bus voltage, power balance, individual and total harmonic distortion constraints defined by IEEE-519 standard. Further, DG penetration analysis was tested on the IEEE-30 bus distribution network using DG scenarios and ten loads. Furthermore, feasibility evaluation of DG installations owned by customers considering protection coordination and power quality was studied. Results demonstrated the efficacy of the proposed method. Moreover, this method can be employed for optimal allocation of distinct kinds of DG in DS thereby achieving a good penetration level.

Yu et al. (2016) presented an approach for sizing and locating Fault Current Limiters (FCL) in mesh networks through nonlinear programming. In this work, sizing and locating FCLs in the power system was achieved by curtailing fault currents to certain levels in breakers' limits irrespective of system size. Furthermore, North-American 395-bus, IEEE 30-bus, IEEE 9-bus were employed for testing and illustrating the proposed approach.

A detailed analysis of DG optimal allocation was presented by (Huy et al., 2017). In this work, optimal DG allocation was analyzed by considering distinct constraints, objectives, and methods. Furthermore, this study highlighted the significance of optimal allocation methods in upgrading the efficiency and accuracy of results. The constraints pertaining to voltage, transformer, DG, current, and power were analyzed. Moreover, methods for optimal DG allocation such as traditional, nature-inspired, society inspired, basic search, and hybrid intelligent schemes were reviewed. Additionally, the advantages and shortcomings of these optimization methods were presented. It was inferred that though analytic methods coupled with simple search present accurate solutions, they are inapplicable for huge networks. Moreover, this study also highlighted that use of hybrid optimization schemes can yield superior outcomes for DG allocation particularly when sustainable resources are considered.

A new approach was presented by Javadi et al. (2013) for enhancing FCL application in retaining relay coordination. In this work, the restoration process was performed without disconnecting DGs or without changing actual relay settings from DSs during a fault. Furthermore, the procedure for choosing the type of FCL impedance and its least value was exemplified. Additionally, two scenarios such as with and without compensator were discussed. Several simulations were conducted for multi-DG and single-DG existence, distinct fault, and DG locations. Moreover, by using three kinds of FCL, this approach achieved appropriate relay coordination even in asynchronous DG systems.

Elmitwally et al., (2015) presented a method for addressing the coordination issue of overcurrent relays in DGs. In this work, overcurrent relays (OCRs) were set to function in a coordinated way for separating faults with reduced implications on customers. Further, this work explored the optimal FCL utilization for maintaining the coordinated operation of OCRs without the necessity of resetting OCRs regardless of the status of DGs. Multi-objective PSO was employed for resolving optimization issues in determining optimal FCLs sizes and locations. This algorithm was then applied to radial and meshed power networks at distinct arrangements of DGs utilizing different sorts of FCLs.

Ibrahim et al. (2017) proposed a new approach for reducing the re-adjusted relays in interconnected power networks during DGs addition with a reduced FCL value. The prime motive of this work was to determine the extent to which the value of FCL impedance could be reduced below its decisive value by re-adjusting actual adaptive relay settings for achieving relay coordination. Moreover, this approach was applicable for any systems/networks regardless of the amount of DGs added and their abilities. This approach was effectively tested and implemented on a huge interlinked IEEE-39 test bus system having 84 relays. Furthermore, results were compared to methods that did not possess re-adjusted settings of relays. Two instances such as the insertion of a single DG and insertion of two DGs simultaneously were considered for analysis. Results illustrated that this approach exhibited better performance than conventional schemes. This approach could be employed for re-adjusting settings of multiple relays and attaining reduced FCL value. This approach succeeded in minimizing the FCL value and achieving optimum substitution with the least total functioning time for end faults of primary relays compared to corresponding values with no variations in relay settings.

An analysis was presented by (Ghaemi et al., 2016) for studying the consequences of FCL on protection coordination and reliability of DS. In this work, the biogeography dependent optimization method was employed for measuring optimal FCL impedance. It was observed that the use of FCL in the network, enhanced network reliability in different aspects. Firstly, it leads to failure rate improvement of protection components, and secondly, it resolved mismatch issue between recloser and fuse in short circuits occurred due to DG in the network and also avoided power cut thereby boosting network reliability.

Hamidi et al. (2018) proposed an approach for optimal DG allocation through optimal FCL sizing for reducing the effect on DS using Nondominated Sorting GA (NSGA-II). The prime motive of this work was to use FCLs in series with DG sections for minimizing the negative consequences of DG units. Reduction in FCLs size was achieved by relevantly allocating DG units in DSs. In this work, an optimization scheme depending on NSGA-II was employed for determining DG unit capacities and its optimal locations, FCLs minimum sizes. Furthermore, this approach was implemented on sample networks. Results illustrated that through suitable DG allocation, FCLs sizes can be decreased considerably.

A framework was proposed by (Dahej et al., 2017) for optimizing the levels of protection coordination and quality of power in microgrids through unidirectional FCLs. In this work, solid unidirectional FCL was utilized as an interface between utility and microgrid for enhancing power coordination and quality of power. The physical constraints of unidirectional FCLs were considered for analysis. Optimization was achieved by setting unidirectional FCL parameters, current and time settings of OCRs. Protection coordination was restored in each connection mode and redundant interruptions were prevented for enhancing system reliability. Furthermore, a fuzzy optimization method was employed for compromising between protection coordination and quality of power, and GA was used for determining appropriate unidirectional FCL features and better OCRs settings.

Jordehi et al. (2016) presented a review on DG unit allocation, that the existing works on DG allocation issues were reviewed for their objectives, applied constraints, DG type, uncertainty modelling type, decision variables, and optimization methods. As a significant finding, it was noted that even though much research is already performed to develop powerful and efficient optimization methods for resolving DG allocation issues, there is still space for enhancement.

A method was presented by (Injeti et al., 2013) for identifying optimal capacity and access points of several DGs in large, small, and medium-scale radial DSs. The prime motive of this work was to reduce power losses in the network, boost the stability of voltage, voltage profile, and enhance loading. Further, performance analysis was conducted on 118-bus, 69-bus, and 33-bus radial DSs for demonstrating the efficacy of the proposed method. Results illustrated that this method was capable of resolving the OPaS issue of DGs with the least computation time.

Kaur et al. (2014) presented a non-linear programming method for optimal positioning of multiple DGs in DSs. In this work, two phases such as capacity planning and siting planning were involved for reducing computational time and search space. The performance of the proposed scheme was validated on IEEE 69-bus and IEEE 33-bus DS for placing multiple and single DG sections that are able to deliver real power or both reactive and real power. Results obtained were then compared to three fundamental categories of optimization methods namely improved analytical, PSO, and exhaustive load flow. Moreover, comparative analysis in reference to computational efforts, distribution loss, and DG size was presented. The prime advantage of this scheme was that it considered multiple DG placement simultaneously offering optimal solutions within less operational time. Additionally, resilience in power factor resulted in attaining improved results.

Esmaeilian et al. (2014) presented a hybrid scheme of heuristic and metaheuristic techniques to shorten runtime and to strengthen robustness for achieving minimum loss in DSs. In this work, forward/backward power flow was adopted and distinct load patterns were considered for analysis. Further, capabilities of the hybrid scheme were validated by performing simulations on different distribution networks such as 83-bus practical DS of the Taiwan power industry and IEEE 33-bus. Moreover, the performance was validated in unbalanced DS such as 33-bus unbalanced DS. Furthermore, reconfiguration and placement of DG were employed simultaneously for minimizing energy loss, examining time-varying features of distinct load types.

Bernardon et al. (2014) presented a methodology for performing intelligent DS reconfiguration incorporating DG in regular operation. The power generation capability of small hydropower, photovoltaic panels, and wind turbines was considered in the reconfiguration procedure. Results illustrated that considerable improvement on performance indicators of the network, minimizing losses, enhancing reliability in reconfiguration procedure of DS was achieved. Moreover, for real-time performance assessment, case studies using real-time power utility data in distinct operating scenarios were analyzed. Results illustrated the feasibility of this method so that it can be implemented in other real-time networks with DG.

3 COMPARISON OF DIFFERENT TECHNIQUES

Table 1 summarizes the important DG research of different authors.

Table 1: Summarized eminent DG research.

Sources	Objectives	Applications	Techniques	Obtained results / Merits	Demerits/Future Scope
Esmaeilian et al. (2014)	1. To enhance the robustness and decrease computational runtime in DGs. 2. To achieve minimum network loss configuration in DS.	Power Distribution Systems (PDS)	GA, Enhanced Reconfiguration scheme	1. Results illustrated the efficacy of the proposed scheme in determining optimal switch status, DG units' sizes and locations in shorter duration. 2. Adjustable with DG placement issue. 3. DG placement and reconfiguration were simultaneously employed by considering time-varying characteristics of distinct load types for energy loss minimization.	This work was mainly concerned with energy loss minimization and runtime reduction, however, for better power networks more factors need to be considered for analysis in the future.

Sources	Objectives	Applications	Techniques	Obtained results / Merits	Demerits/Future Scope
Srivastava et al. (2016)	1. To determine optimal relay settings occurring due to changes in environmental conditions affecting DG performance. 2. To determine the effectiveness of appropriate relay coordination.	PDS	Hybrid PSOGSA	1. Achieved desired relay coordination. 2.Environmental factors like cell temperature, wind speed variations and solar irradiance variations were considered for analyzing their effects on relay coordination.	Further research needs to be conducted by considering more environmental factors and their impacts on optimal relay settings.
Sultana et al. (2016)	1. To resolve the optimal allocation of DG in DS. 2. To validate the effectiveness and feasibility of KH on 118-bus, 69-bus and 33-bus radial DS.	PDS	Kill-Herd (KH) method	1.Investigated complex issue of DG sizing and locating for energy loss reduction in radial DS. 2. Minimized power loss by installing DG in an optimal location.	Led to local convergence rather than global convergence due to optimal tuning of particular input parameters and incorrect parameter settings.
Sultana et al. 2015)	1. To resolve optimal DG placement issue in DS. 2. To enhance convergence speed.	PDS	Oppositional KH (OKH) method	Exhibited better performance with respect to convergence property, computational time, energy loss and solution quality.	Integration of OKH with other methods and their validation for attaining better results needs to be conducted.
Srivastava et al. (2017)	1. To achieve proper overcurrent relay coordination for the DG system. 2. To avoid unwanted outages and malfunctioning of relays during DG penetration.	PDS	GSA, PSO	GSA exhibited better performance with respect to relay coordination.	Further improvement is required for attaining better outcomes by combining different schemes.
VC (2018)	1. To reduce loss in DS by optimal DG sizing of resources. 2. To enhance voltage profile.	PDS	Ant-lion Optimization (ALO)	ALO exhibited better performance by decreasing power losses and attaining a better voltage profile.	Further research needs to be conducted by considering different transmission buses for attaining better results.
Bohre et al. (2016)	1. To achieve optimal DG positioning and sizing with loads.	PDS, Practical distribution networks	PSO, GA	1. Minimized power losses. 2. Improved voltage profile, economic benefits, reliability, load balancing ability of the system and transfer capability.	There is still scope for improvement.
Yang et al. (2017)	1. To determine optimal FCL positioning in minimized search space. 2. To resolve the optimal FCL positioning issue by optimizing FCL parameters.	Smart grids, Power networks	The hierarchical fuzzy logic decision, Hash-integrated generic method, PSO	1. Exhibited better performance using lesser FCLs for fulfilling all constraints. 2. This approach was applied to a realistic power network for resolving faulty current problems pertaining to excess capacity.	Further research pertaining to cost allocation owing to FCL installation needs to be explored.
Mohandas et al. (2015)	To determine optimal DG sizing and location for enhancing voltage stability.	PDS	Chaotic Artificial Bee Colony (CABC)	1. Reduced reactive and real power losses and enhanced system voltage profile. 2. Achieved considerable improvement in speed.	More factors influencing DG performance need to be studied and validated.
Mohanty et al. (2016)	To determine optimal DG size and location by considering voltage stability, actual power loss and voltage profile in DS.	PDS	Teaching learning-dependent optimization method, PSO, GA	1. Analyzed performances of test systems with and without DG installations. 2. Achieved better performances with proper DG placement.	1. Further research by considering distinct kinds of DG need to be investigated. 2. Fixed capacitors in addition to DGs can be employed for achieving better outcomes.
Kanwar et al. (2017)	1. To determine optimal DG allocation and network reconfiguration in radial DS. 2. To boost the convergence and accuracy of optimization schemes.	PDS	Intelligent search dependent teaching-learning optimization	1. Improved solution quality and reduced CPU time. 2. Network reconfiguration enhanced the goals of DG installation.	Further research needs to be conducted for optimally placing distributed resources with intermittent generations.

Sources	Objectives	Applications	Techniques	Obtained results / Merits	Demerits/Future Scope
Abdmouleh et al. (2017)	1. To analyze economic, technological, environmental, regulatory and technical factors on DG integration. 2. To study optimization methods for resolving optimal DG allocation matter.	Power networks, Smart grids	Harmony search, Ant colony, GA, Tabu search, PSO, Simulated Annealing, heuristic and hybrid heuristic schemes	Presented latest published works on the application of distinct optimization schemes for resolving allocation issue of DG in power networks.	1. Only static distribution networks were used. Hence dynamic models need to be used for addressing future DG planning. 2. Uncertainties in load forecast, oil prices, solar and wind generation, etc. need to be considered in addition to OPaS of DG.

4 Future Research Ideas

It is clear from the study that for determining the global optimal substitute of a multi-objective, use of hybrid methods by combining two or more optimized intelligent schemes confers a more reliable and effective optimal solution. The novel optimization and the smart transformer-based control can also be used for a better outcome. Some of the ideas which can be explored are:

1. Only static distribution networks were used. Hence dynamic models need to be used for addressing future DG planning.
2. Further research needs to be conducted for optimally placing distributed resources with intermittent generations.
3. Investigation considering distinct kinds of DG can be done.
4. The impacts of the environmental factors on optimal relay settings can be taken into account for better outcomes.

5 CONCLUSION

The review paper provides a brief overview of DG. The study focuses on the DG design constraints, DG benefits, various design challenges, reliability requirements, and factors affecting DG in DS models. In this study, a comparative analysis is presented based on the objectives and applications of different DG techniques, and the observations and future scope are tabulated. As a significant finding of this study, it was noted that even though much research is already performed to develop powerful and efficient optimization methods for resolving DG allocation and control issues, there is still space for enhancement. By appropriately reviewing existing research outcomes it is clear that for determining the global optimal substitute of a multi-objective, use of hybrid methods by combining two or more optimized intelligent schemes confer a more reliable and effective optimal solution. Moreover, an efficient DG system can be developed by using novel optimization methods and smart transformer-based control for achieving better outcomes by addressing the challenges reviewed in this paper.

6 Availability of Data and Material

Information can be made available by contacting the corresponding author.

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